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TECHNICAL NOTE

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SUN TRACKING BY THE MINITRACK NETWORK STATIONS

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SUMMARY

Meridian transits of the sun have been recorded daily on a frequency of 108 Mc by the Minitrack network of stations. By comparing the position of the solar noise center, as found on the record, with the predicted position of the optical center, the displacement of the 108-Mc emission point from the center of the solar disk is determined.

A number of stations may track the sun simultaneously. Analysis of the data from these stations shows that in approximately 75 percent of all passes the polar coordinates of the noise center as observed by these widely separated stations are in good agreement.

D-1121

CONTENTS

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INTRODUCTION

The Minitrack tracking network was designed for the precise tracking of artificial satellites. There are 13 stations in operation as of this writing. Since the end of 1957, the Minitrack network has frequently tracked the sun and the radio stars Cygnus A and Cassiopeia A during their meridian crossings. Tracking has been conducted almost daily since December, 1959.

APPARATUS

The Minitrack system originally operated at a frequency of 108 Mc; but a 136-Mc frequency range was added in 1961. The basic 108-Mc interferometer arrangement (Figure 1) is in the form of a cross and has 54.9 wavelengths between antenna pairs. Each antenna ground screen measures 60 feet in the east-west direction and 10 feet in the north-south direction. The two antennas at the ends of the north-south leg provide the north-south fine measurement, and the two at the ends of the east-west leg provide the east-west fine measurement. Each antenna has a gain of 17.9 db. Because the north-south antenna 3-db beamwidth is 76 degrees, two sets of ambiguity resolution antennas are required in this direction. The 8-degree east-west 3-db beamwidth requires only a single antenna pair for ambiguity resolution.

Because the system is linearly polarized in the north-south direction, a 3-db loss is incurred if the source has random polarization. Also, for linearly polarized sources, losses may occur due to rotation of the plane of polarization by the ionospheric Faraday effect.

The signals received at the two antennas are fed to two separate preamplifiers through nearly 300 feet of nitrogen-filled coaxial line which is about 2 feet underground to have a

*This paper was presented at the XIII General Assembly of the International Scientific Radio Union, University College, University of London, London, England, by Dr. Robert J. Coates of the Goddard Space Flight Center.

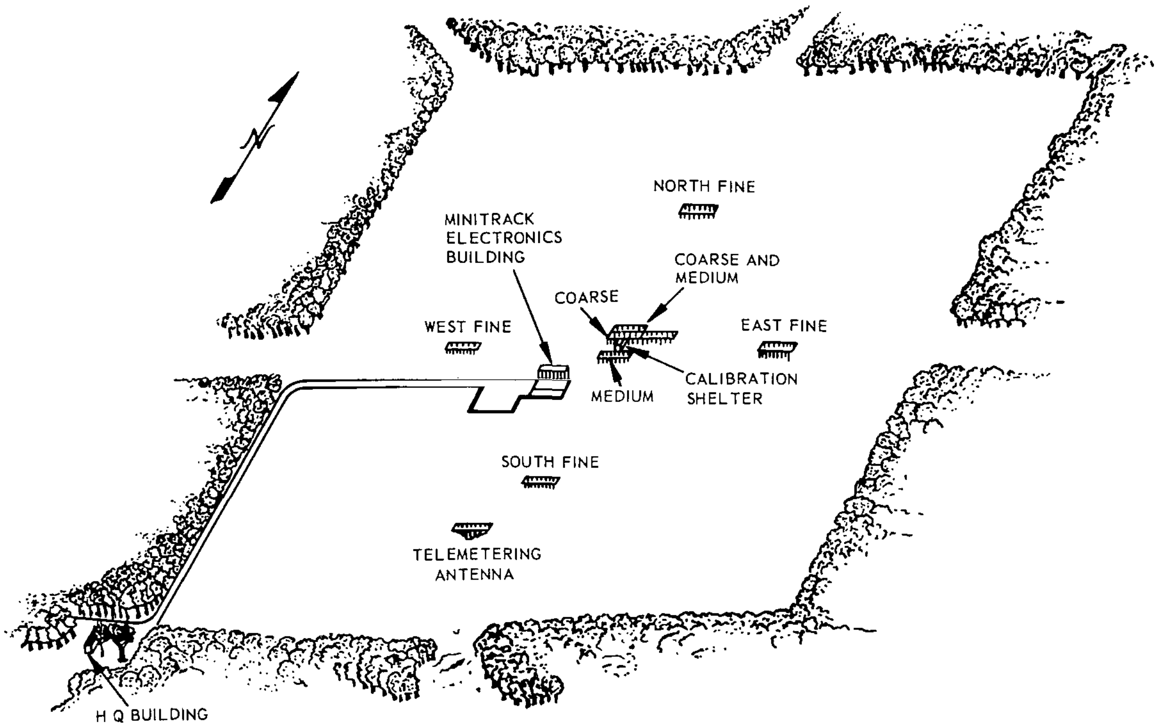

Figure 1 - Basic arrangement of a Minitrack ground station

nearly constant temperature. A block diagram of the Minitrack receiver is shown in Figure 2. After preamplification, the signals are fed to the first mixers and converted into the two first IF signals, separated in frequency by 500 cps. This is accomplished by phase-locking the 500-cps difference of the special local oscillator output frequencies, 119.2950 and 119.2955 Mc, to a 500-cps standard frequency from the time standard chassis. The two IF signals of 11.2950 and 11.2955 Mc are then combined in a simple adding circuit and amplified in a low-gain 10-Mc IF amplifier stage. The combined signals are converted to 469.5 and 470.0 kc in a second mixer and once again amplified; but this time by the system's primary amplifier, where the bulk of the system gain occurs. The 10-kc bandwidth of this amplifier determines the predetection bandwidth of the receiver, and since the latter bandwidth is relatively broad compared to the 500-cps separation of the combined signals, very little differential phase error is introduced. The combined output feeds a square-law detector, which reconstitutes a 500-cps signal. This signal is passed through a 10-cps postdetection filter centered on 500 cps. Between this signal and the 500-cps difference frequency from the special local oscillator unit, there is a phase difference which is identical to that existing between the two initial 108-Mc signals received at the two antennas. This phase difference is converted to an analog voltage output whose amplitude is directly proportional to the phase difference and is displayed on a Sanborn direct-writing recorder.

D-1121

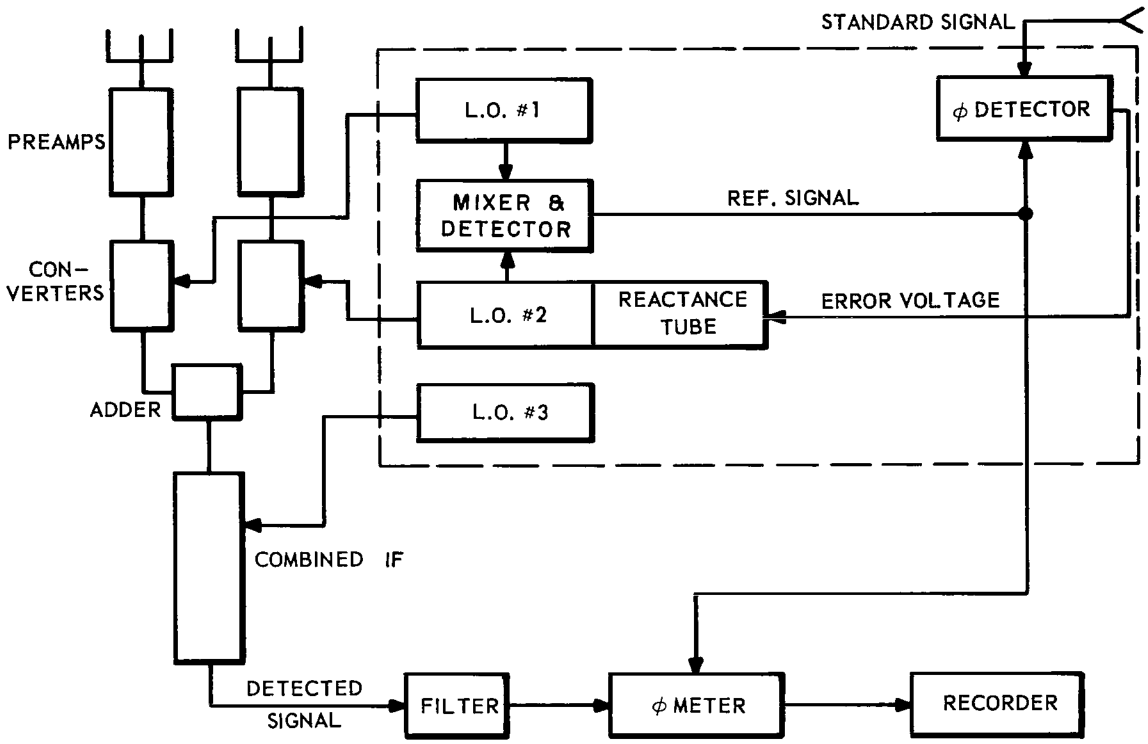

Figure 2 - Block diagram of the Minitrack receiver

CALIBRATION

Each station is calibrated at least three times a year by optical means. A sidereally-driven camera with an f/5.0, 40-inch focal length lens, situated in the center of the antenna field, photographs a high flying aircraft carrying a Minitrack transmitter and a flashing light against the star background on a clear night. The light flashes in a time-coded sequence and the time of each flash is known to within 1 millisecond. As the flashing light is photographed the 108-Mc transmissions from the airplane are recorded by Minitrack as a function of time. The positions of the flashing light are measured relative to the adjacent stars, and a precise position determination can then be made for the time of each flash. These optical positions are correlated with the Minitrack recordings to provide the calibration. The accuracy of the optical determination of the light's position is estimated to be better than 2 seconds of arc, or a factor of ten better than the design accuracy of the Minitrack system (about 20 seconds of arc for signals stronger than -120 dbm at the input to the receivers). Frequent internal calibrations of differential phase drift in the system electronics, as well as the radio star meridian crossing data, help to determine any drift in the system between airplane calibrations.

METHOD OF OBSERVATION

The sun is tracked by all the Minitrack stations, including four within $\pm 5^\circ$ of longitude 78° west and two within $\pm 30'$ of longitude $70^\circ 30'$ west. Since tracking begins 20 minutes before local apparent noon and ends 20 minutes after, the four stations near 78° west can track the sun simultaneously for a period of time, and the same is true for the two stations near 70° west. With simultaneous tracking by widely separated stations, any local atmospheric or ground disturbance causing enhanced radiation at one station and not at others can safely be ignored.

Figure 3 shows a Minitrack record of an unusually strong solar pass at -101 dbm. The solar track is recorded on an eight-channel analog-type Sanborn recording, which also has a special time recording channel. Two channels carry the fine measurements of the source position, three channels have the ambiguity resolving tracks, and the three remaining channels have the signal level of the source at the receiver input in dbm. The paper speed is usually set at 2.5 mm/sec, and therefore times can be read to the nearest second. The speed may be increased to give readings accurate to within 0.1 second, but this is done only when the signal-to-noise ratio is high. Figure 4 shows two short solar bursts recorded simultaneously by the two stations near longitude $70^\circ 30'$ west (Santiago and Antofagasta, Chile) on March 25, 1960. Figures 5 and 6 show a longer burst recorded simultaneously by the same two stations on March 10, 1960.

Any sources within the beam pattern which are transmitting at 108 Mc and have signal strengths greater than the Minitrack threshold will be detected by the system. Their positional components are added vectorially and weighted according to their signal strengths. Solar bursts recorded on the Sanborn recorder average -120 dbm and very few are weaker than -130 dbm. Therefore it is believed that the strongest radio star sources, with signal levels of about -140 dbm, should have very little effect on the determination of the emission point of a solar burst. However, since the background noise of the quiet sun is also about -140 dbm, its apparent position will be influenced by the presence of a strong radio star. It should be noted that the minimum signal level from which a positional determination of a source may be made is about -140 dbm.

There are also times when two or more solar flares are causing 108-Mc emission at nearly the same signal level. Then the position determined by the Minitrack stations will not correlate with the position of any one flare but rather with a mean position for all.

The position of the center of the sun is predicted at one second intervals for the period of time the sun is within ± 5 degrees of meridian crossing at each station. A number of positions are read off the Minitrack record during a pass (for both the quiet sun and solar bursts) and are compared with the predicted positions. The north-south and east-west differences are then converted to polar coordinates r and θ, with the origin at the center of the sun and θ measured eastward from the north point of the solar disk, to locate the position of 108-Mc emission on the plane containing the disk.

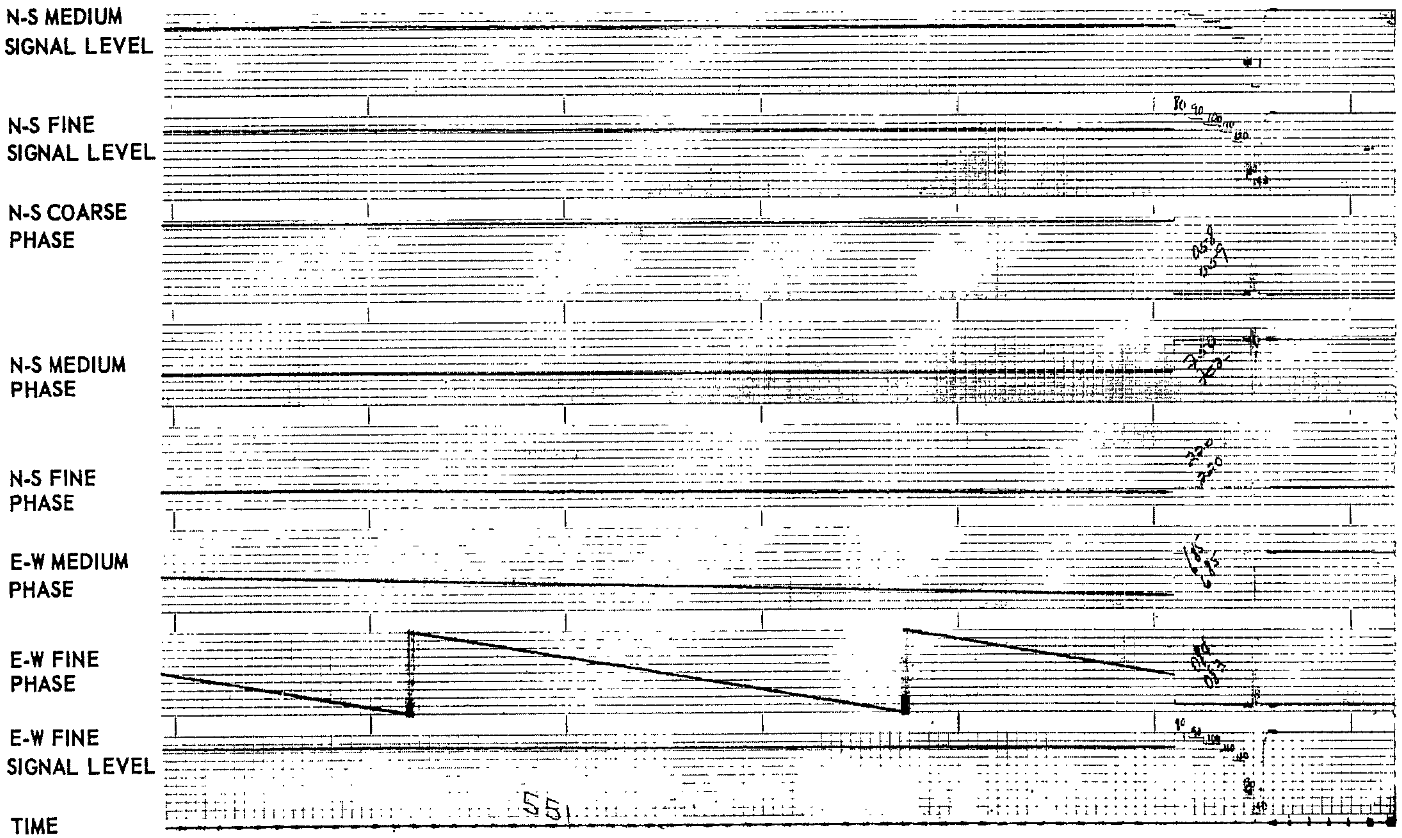

Figure 3 — Antofagasta, Chile, Sun Track of March 30, 1960 for -101 dbm solar meridian crossing

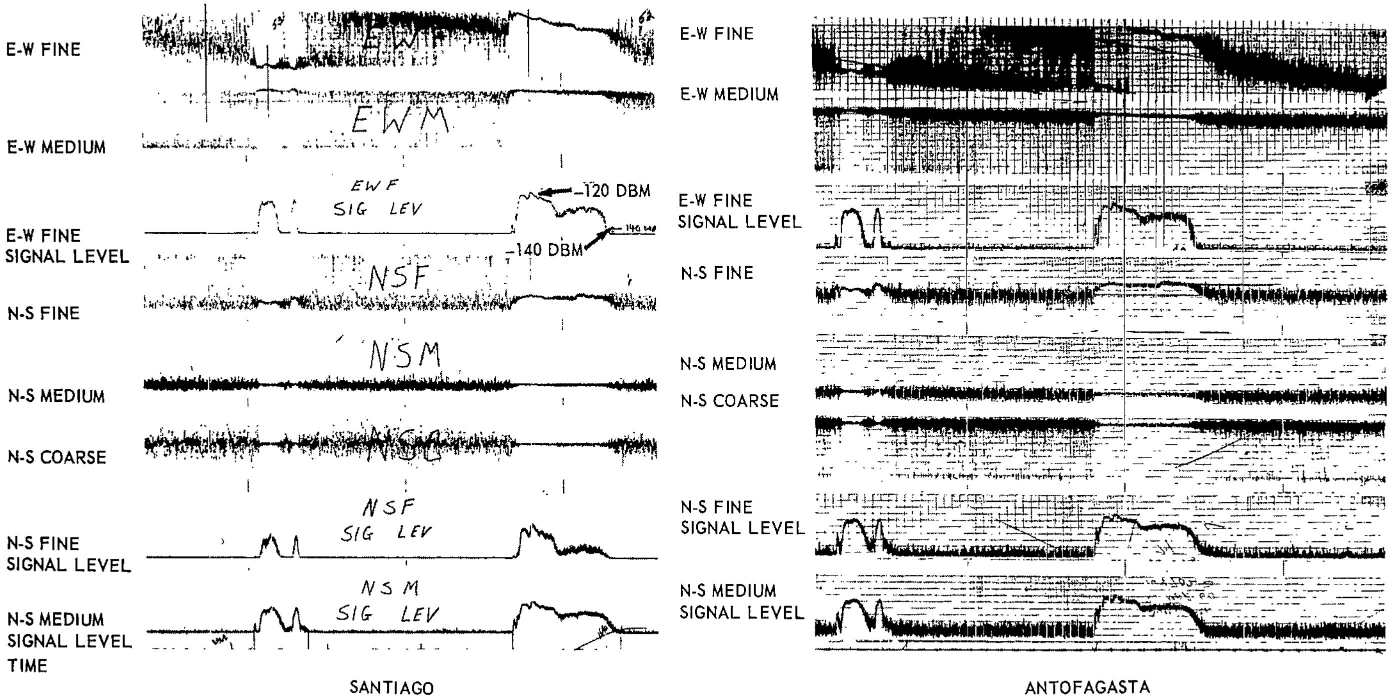

Figure 4 — Minitrack record of two short solar bursts, taken at Santiago and Antofagasta, Chile, on March 25, 1960

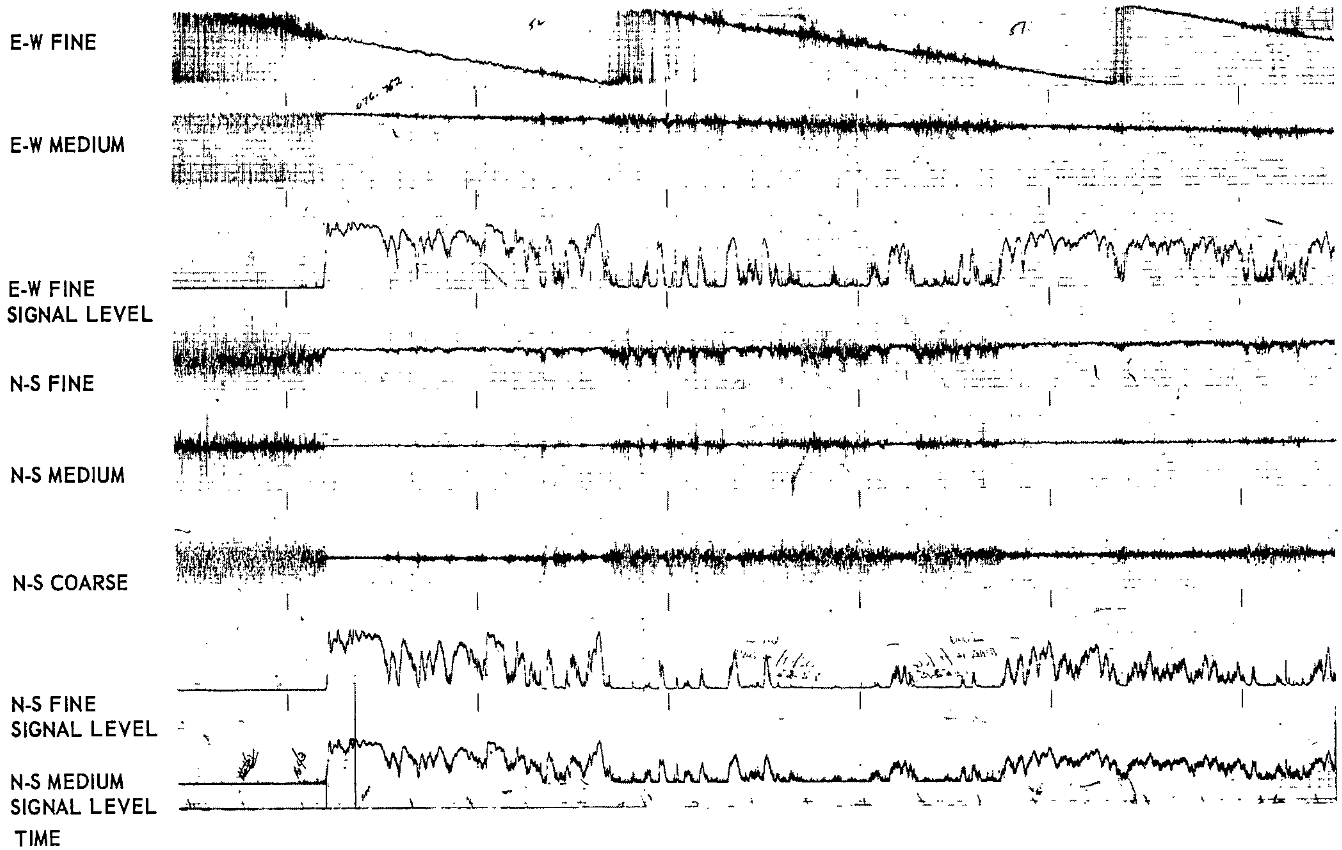

Figure 5 — Minitrack record of a long solar burst, taken at Santiago, Chile, on March 10, 1960

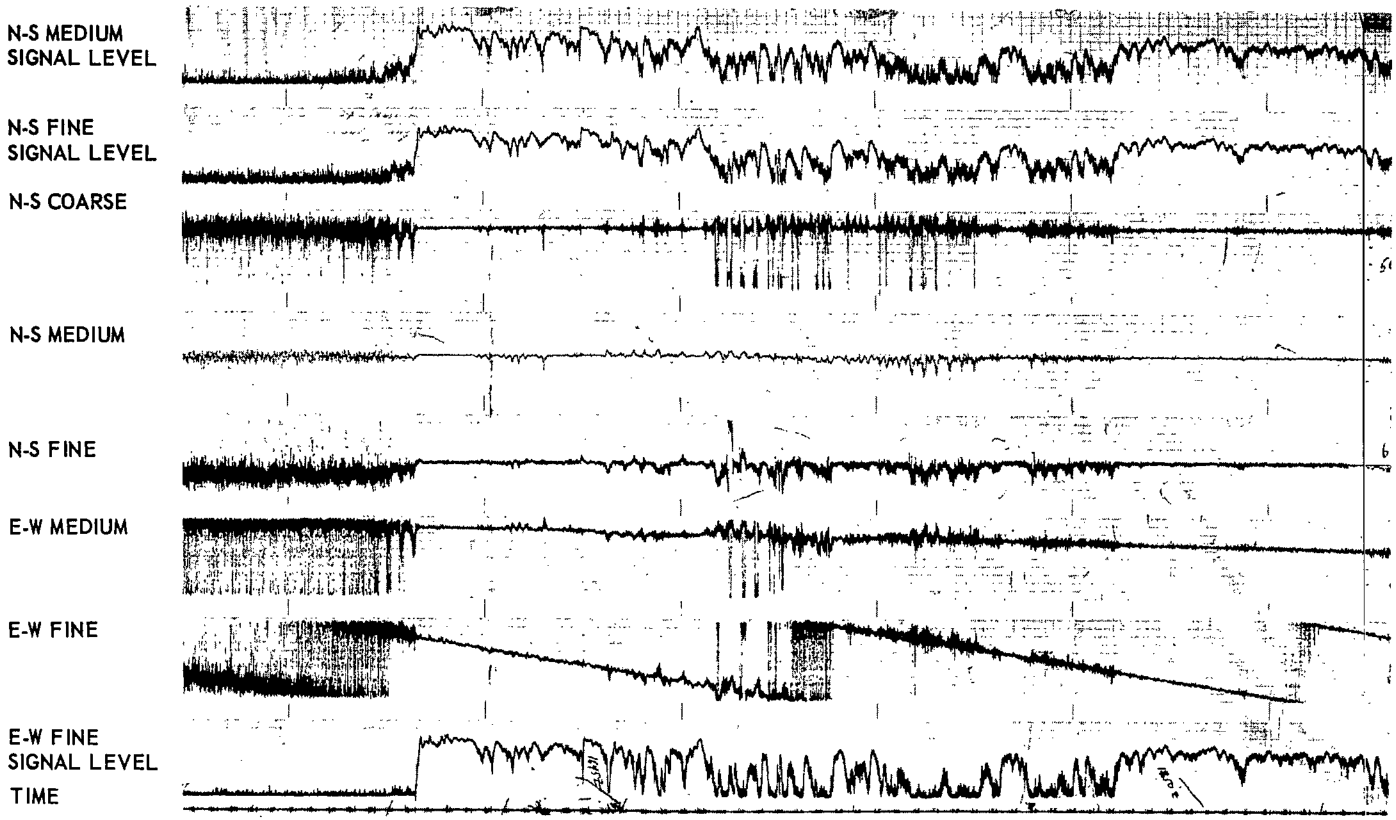

Figure 6 — Minitrack record of a long solar burst, taken at Antofagasta, Chile, on March 10, 1960

Figure 7 depicts selected r and θ determinations made on nine days during May, 1960, for three of the four stations near longitude 78° west. The position readings taken from the Minitrack records are, in all cases, for the time when the sun was crossing the meridian of the Quito, Ecuador, station. The r and θ determinations for the different stations do not always agree as well as those shown here, and it is assumed that localized ionospheric and ground disturbances account for the poorer correlations. However, correlations as good as these are obtained for about 75 percent of all passes. The average angular dispersion of these source determinations by the three stations near 78° west is only 1 or 2 minutes of arc. It is interesting to note that the apparent 108-Mc source centers for May 12 and May 14 lie entirely off the visible disk of the sun.

Since 108-Mc emission from the sun originates in the Corona, it is conceivable that intense activity in a particular region of the Corona could move the apparent source center off the visible disk as observed on these two days. Even when the source center appears on the visible disk in the polar coordinate projections, it is usually well off the sun's surface in three-dimensional space.

On days when the minimum signal level of -140 dbm is received (as on May 3, 22, 29, and 31), the sun is relatively inactive and one might expect the position of the apparent source center to be relatively stable. But this is not the case. Even on these quiet days the 108-Mc apparent source center moves in an apparently random fashion and may lie anywhere on the solar disk. Therefore, the sun is not suitable as an independent 108-Mc calibration source, but can be used to compare calibrations between stations which are able to track it simultaneously.

It is hoped that more detailed analysis of the data on solar bursts will ultimately permit positional correlations of these bursts with other solar events.

ACKNOWLEDGMENTS

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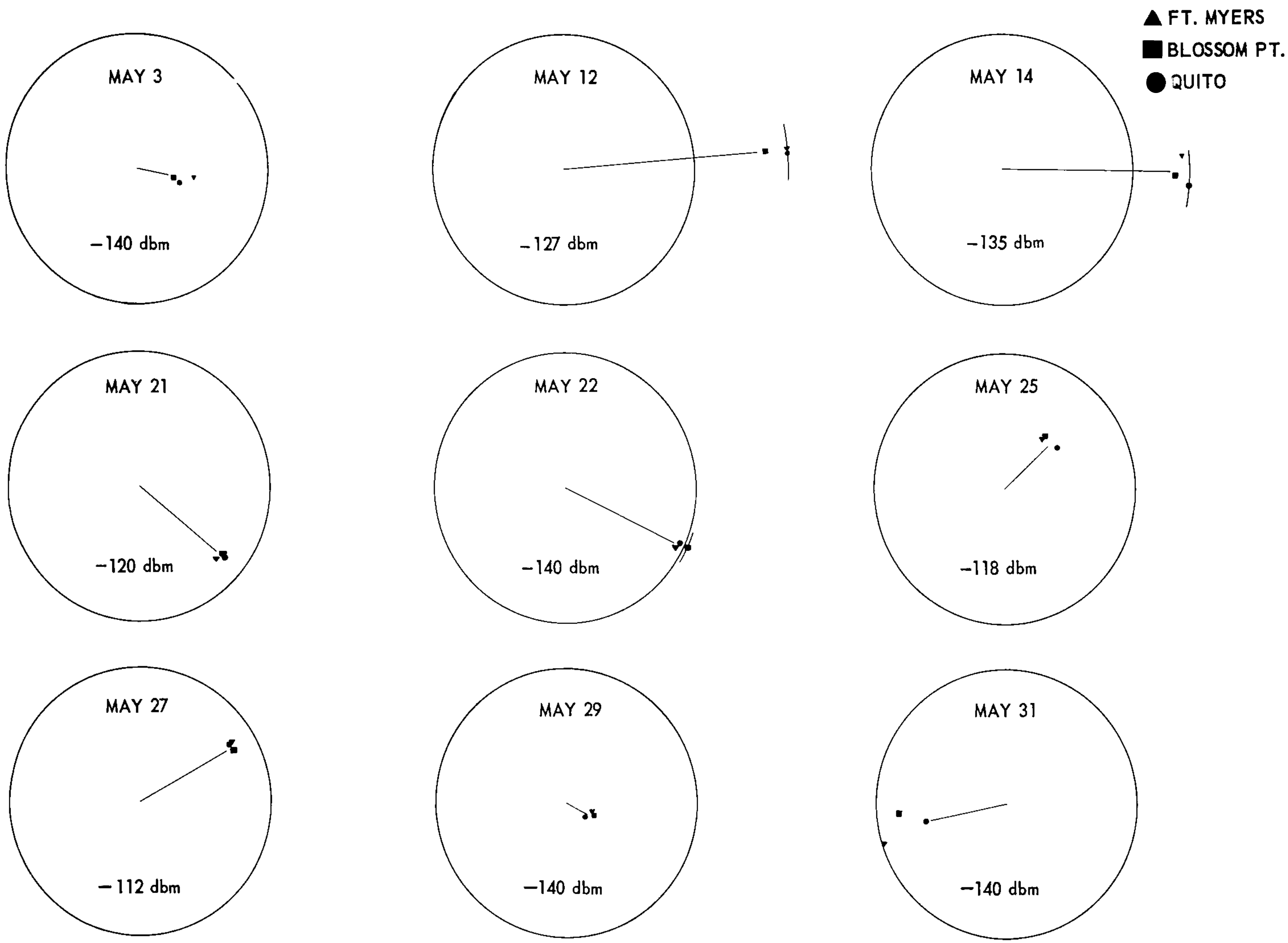

Figure 7 — Position determinations of solar noise center for nine days in May 1960

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